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Dust storms and dust-sand flows over the earth's surface, as well as altitudinal dust transport over immense distances, are characteristic of arid and sub-arid regions of different earth continents. These phenomena are widespread in North Africa and the Near East. Due to a very small number of meteorological stations and scarce and dissimilar observational data by individual investigators, the general regularities of the dust-storm and dust-sand-flow distribution over Africa and Arabia and their relationship with the composition of soil surface and the relief orientation are not sufficiently studied. Earth imagery from space has played an important part in meteorology in studying cloud cover. In the same manner, we have used the earth photographs obtained from different space vehicles for studying the dust-sand "cloudiness." Among these are the global earth photographs from space probes Zond-5 and Zond-7 at a scale of 1:25,000,000 and TV images at a scale of 1:15,000,000 from meteorological satellites ESSA-8 and ITOS-1 received through the APT system at the receiving satellite station at Leningrad University. Local space photographs from manned spacecraft Gemini and Soyuz were interpreted at scales of 1:500,000 to 1:1,000,000 along with aerophotographs of the same areas. Both were used for determining the relief structure and orientation of the longitudinal dunes within the extension of these flows. A study of the regional images of the dust-sand flows from local photographs of the relief structure and from data obtained from the meteorological network produced the following results:

1. The global photograph from Zond-5 September 9, 1968 (Figure 1a) fixes the meteorological situation connected with the dust-sand storms in South Sahara embracing the deserts and desert-savannahs from Senegal to Sudan. Here, at the point of junction of the hot northeast Charmatan with the cool and moist west southwest monsoon ascents, a large amount of the solid dust material at certain heights is carried away by strong northeast flow (Vinogradov, 1970, Carlson, 1969, Frank, Johnson, 1969). Within South Sahara,

the winds affect sand deserts Mareina, Accle-Avana, and Makteir in Mavritania and Niger. Here, the dust-sand material raised in the air forms zones of high dust turbidity which are represented in the photographs by a light gray spot with diffuse boundaries masking the image of the earth's surface (figure lb, H_1). The Adrar Ifaraz plateau is composed of dark colored rocks. Quite obvious are the straight, light gray, superimposed sand ridges and streams (oriented from east-northeast to west-southwest) of the transit dust-sand material carried near the surface. The flow terminates in savannahs of the Niger River and the deserts north of Chad Lake. In the Bodel cavity, one can recognize the second local vorticity from the light gray spot with diffuse boundaries (Figure lb, H_3).

A fragment of the global color photograph of Northeast Africa and the Near East taken August 8, 1968, from Zond-7 over the Arabian peninsula and adjacent areas fixes two macro-scale dust-sand flows identified over the Red Sea and the Persian Gulf from the whitish strip against the dark background of water surfaces. The flow over the land is less pronounced. The interpretation of the dust-sand flow movement from space imagery was followed by the analysis of quasi-synchronous data from ground meteorological observations (Grigoriev, Lipatov, Vinogradov, 1971). The zone of the dust-sand flow movement corresponds to the large sand areas, viz., the desert Great Nafud, Dehna, Rub al Khali. In these sand deserts, different types of eolian relief are developed; however, the ridge of seifs is prevalent. The extension of these huge longitudinal dunes in separate regions of Arabia is evident from interpretation of local space photographs from manned spacecraft (Mehr Moor, 1968, Grigoryev, 1970). Comparison of the distribution of the dust-sand flows and the longitudinal dunes reveals agreement in the orientation of seifs and wind flows over the whole distance of their movement. Seifs of the desert Great Nafud oriented from northwest to southeast are followed by the seifs of the Dehna desert whose direction near the junction with the desert Rub al Khali is changeable; in the desert Rub al Khali, the longitudinal dunes are oriented first in the north-northeast, south-southwest direction and then from northeast to southwest. Each single seif is part of a giant system of seifs from the same origin, viz., by the presence in this region of permanent winds of stable direction.

Dust-sand flows are obvious not only in global space photographs but in TV images from meteorological satellites ESSA and ITOS (Prospero, 1970). The latter is of particular importance since it permits the study of dynamics and periocity. The dust-sand flow is distinct in the TV image of the lowland of the Euphrates and Tigris Rivers and the northern part of the Persian Gulf. The picture was received by the Leningrad University station July 17, 1970, from the American meteorological satellite ITOS (Figure 2). The flow is represented by several strips (four are recognized) lighter than the surface of the valley. The extension of these strips is most pronounced against the dark background of the Persian Gulf. How far the surface is masked by the dust-sand flow is seen by comparing TV pictures received on other days when the flow was missing. Analysis of the meteorological data for 3 hours July 18, 1970, showed the prevalence of the northwest winds related to the trade wind flow over the west periphery of the baric depression. The strongest winds blew over Mesopotamia, the northern part of Arabia and the Persian Gulf. This persisted up to the height of 5 km. A strong northwest wind particularly intensive in the daytime and carrying dust and sand in summer is called "Great Chamal."

Comparison of the meteorological data with the dust-sand flow in the TV picture, study of densitometric profiles of the dust-sand flow, and analysis of the composition of loose deposits and the character of the soil mantle of the regions over which the dust-sand flow is formed permit the study of its structure. The dust-sand flow becomes visible in the picture southeast of lakes El-Milkh and Milet-Tartar, i.e., where the wind flow is more intensive and carries a greater number of dust particles of surface deposits. Within the Tigris and Euphrates lowland, in contrast to the adjacent deserts of North Africa, very fine alluvial deposits subjected to wind erosion are prevalent. The dry lake bottoms also produce dust, though in a lesser degree.

In the TV image of the dust-sand flow over Mesopotamia (Figures 2a and 2b), one can see the brightest strip which passes over the comparatively narrow (10-25 km) zone stretched from northwest to southwest along the flow movement. This zone of loose sands of Az Rakhab, the edge of Mesopotamia lowland, consists of separate areas with a general extension of more than 200 km. The origin of the thickest stream of the dust-sand flow seen in the TV picture is associated with the dispersal of loose sands. The smaller air streams over the central and northern parts of the lowland contain a good deal less suspended material since they lash over the lakes, bogs, solonchaks (salt soils), and relatively looser watersheds.

Analysis of the densitometric profiles of film images plotted along and across the flow over the land and the water surface enabled recognition of the dust turbidity over different surfaces and more detailed study of its structure.

We have isolated four gradations of the dust atmospheric turbidity. A weak dust turbidity slightly affects the background density, decreasing the albedo value by less than 9 percent. A moderate turbidity essentially masks details of the surface and retains only the details of high contrast (K=0.7-0.3), decreasing the albedo values by 9-12 percent. The mean turbidity strongly masks the details of the landscape though the image tone of the underlying surface still affects the image tone of the flow. Due to this turbidity, albedo is lowered by 12-18 percent. Finally, a strong dust turbidity has an albedo of 18-25 percent and entirely masks the underlying surface.

Since the image density for the dust-sand cloud does not exceed that of the clay-sand desert with the albedo of 25-30 percent, it can be detected only against the background of the surface having an albedo less than 20-25 percent, i.e., against the background of the sea, oases, moist solonchaks, vegetating plants, dark-color soils, and the outcrops of dark-color rocks with an albedo of 5-15 percent. A study of densitometric profiles of the dust-sand flows permits one to detect, from the changes of optical density, the presence of the atmospheric dust turbidity over different surfaces.

Of interest is a stream-like structure of the dust-sand flow. The TV space image from the altitude of 1,400 km revealed the largest streams--macro-features of the flow structure. About the structural complexity of the dust-sand flows, similar to those fixed in the TV image, one can judge from the aerophotograph one of the flows of the adjacent territory of Mesopotamia (Combie, 1937). The aerophotograph from a height of about 2 km shows a multi-stream structure of a part of the dust-sand stream--meso-features of its structure.

3. Local photographs from manned spacecraft also reflect the presence of atmospheric dust-sand flows (Wobber, 1969). In most cases, the dust turbidity is superimposed in the form of a uniform haze over the whole or a major part of the photograph, masking the surface details or considerably decreasing the contrasts of their imagery. Such photographs contain little information on the dust-sand flows since the latter are too extensive, up to several hundred kilometers, and, therefore, numerous local photographs covering several tens of kilometers would be needed for their study.

In local photographs, one can see the details of the wind-sand flows and their relationship with the relief. For example, in the photograph of the Lebian desert, south of oasis Kharga a thin structure of the wind-sand flow is observed: separate streams up to one kilometer wide extending over several tens of kilometers, breaks of the flow above the depressions with oases and the fixed soil surface, bending of elevations, sharp destructions along the erosional ledges, and many other details.

Conclusion

Dust-sand wind structures are a widespread phenomenon in regions with active wind-erosion processes in the arid and sub-arid zones. Their dimensions can attain several thousand kilometers. Global photographs are perspective for a study of the dust-sand flows of maximum extension (more than 1,000 km) and for the fixation of separate dust structures in the latitudinal systems (Figure 1). Regional TV images provide most valuable information on the dust-sand flows and storms (whose extension normally reaches several hundred kilometers) and on their relationship with a meteorological situation (Figure 2). Local photographs contain a smaller amount of information, as a whole, but may be helpful in studying a thin structure and, in particular, the influence of topography soils, vegetation and moisture. In practice, aerophotographs are not important for studying the wind-sand flows and dust storms, though some of the illustrations may be useful (Figure 3).

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FIGURE 1a. Fragment of global photography of the South Sahara and Sudan received from the space probe Zond-5. (Scale: about 1:20,000,000)

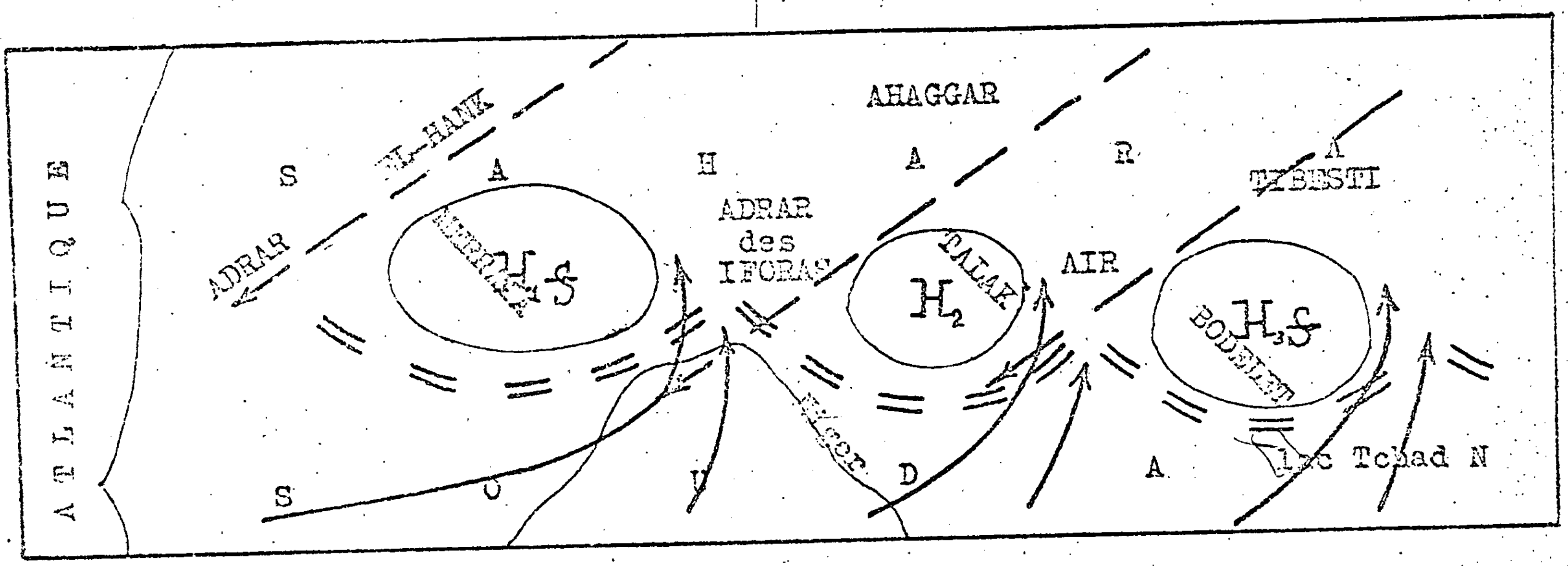

FIGURE 1b. Scheme of interpretation of the global photography (Figure 1a).

Legend: Double line is a zone of the inter-tropical convergence; H are the centers of baric depressions; solid lines are wind axes of monsoon air masses; dotted lines are wind axes of the trade air masses; S are the dust storms.

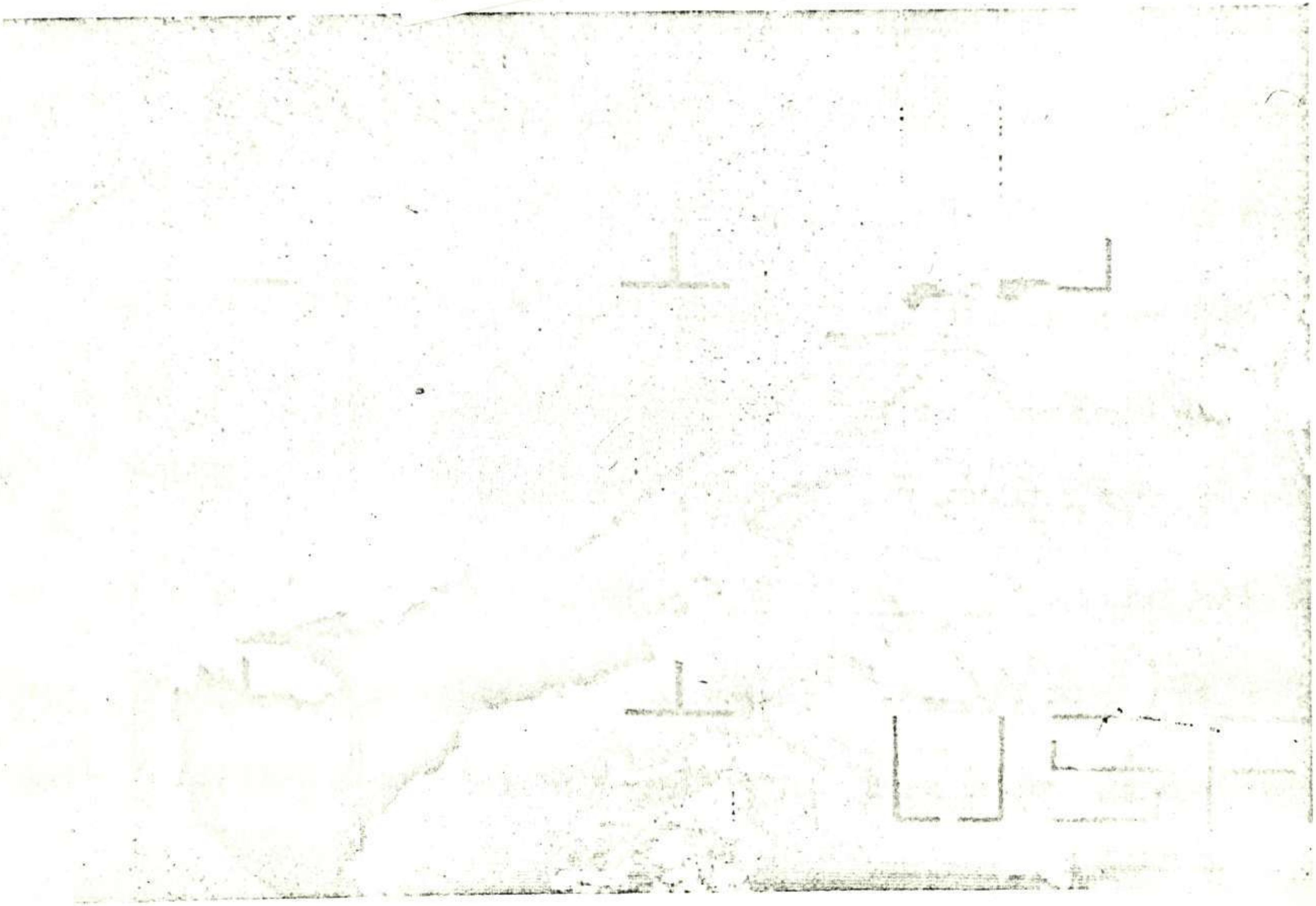

FIGURE 2a. Regional TV image of the Mesopotamia lowland received from the ITOS-1 satellite July 17, 1971. (Scale: about 1:5,000,000)

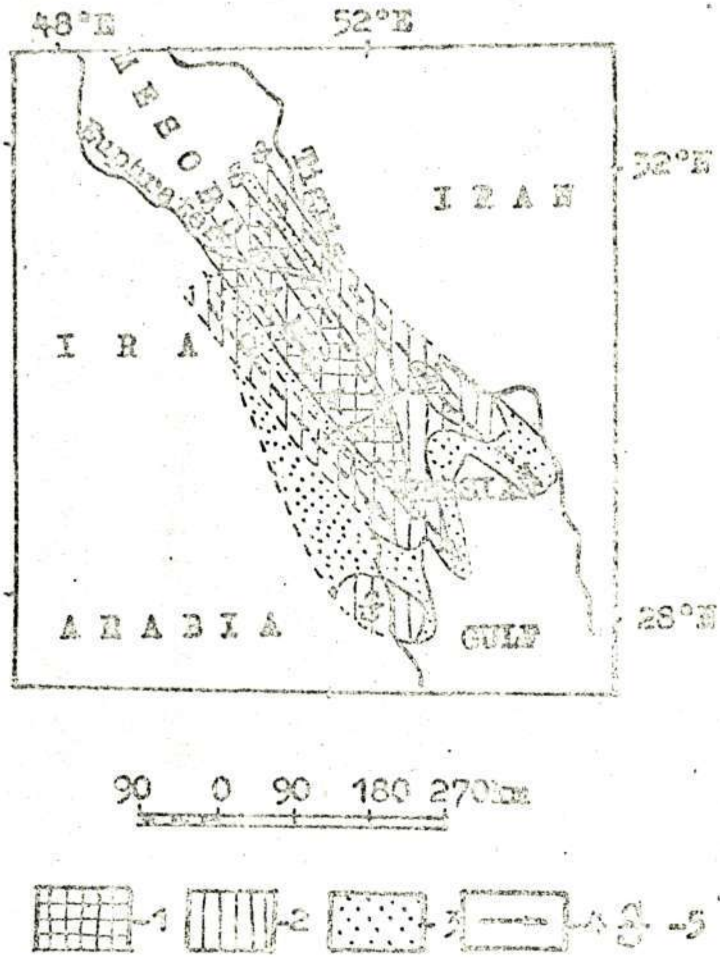

FIGURE 2b. Scheme of interpretation of the TV image (Figure 2a).

Legend: (1) high atmosphere optical density; (2) middle density; (3) moderate density; (4) wind axes of the dust flows; (5) dust storms.

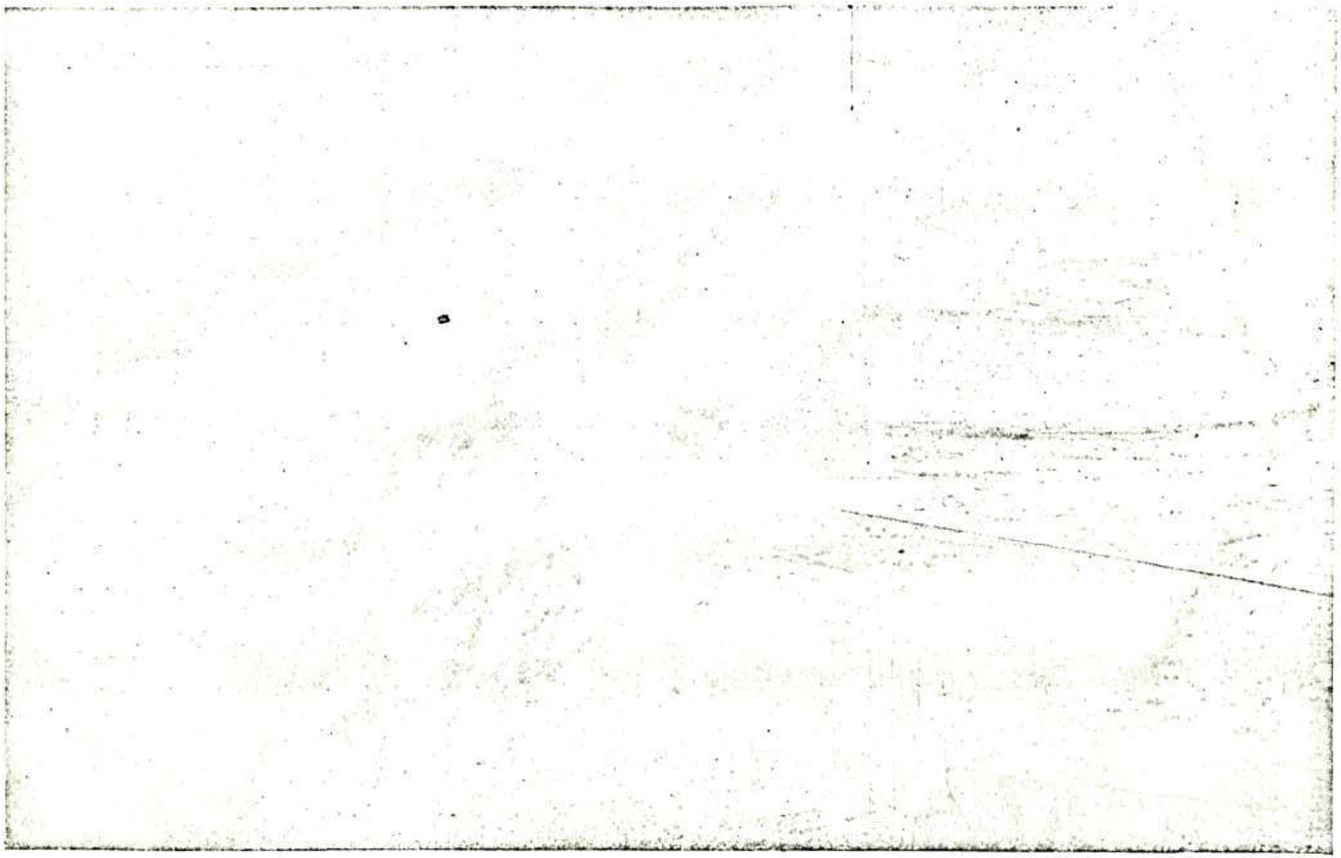

FIGURE 3. Oblique air photography of the dust storms in the Mesopotamia lowland.